

# **Swept Frequency Acoustic Interferometry (SFAI)**

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# Techniques for Noninvasive Probing of Liquids Inside Sealed Metal Containers

## Optical

Cannot penetrate object

## Electromagnetic

(RF, microwave)

Cannot penetrate object

## Thermal

May be able to determine liquid thermal conductivity

Impractical, unsafe



## Nuclear

Can only determine elemental information e.g., H, Cl, P, etc.

Requires radioactive source, LN<sub>2</sub> cooled detector, and long sampling time (~30 min)

## Acoustic

Can identify liquids based on physical properties - <20 s

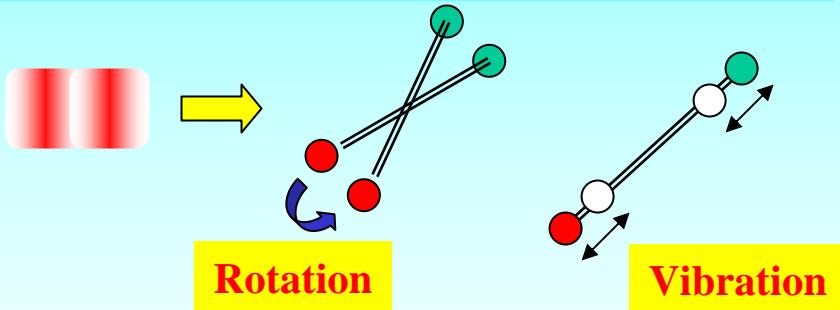
No chemical or elemental information

# PHYSICAL PARAMETERS THAT CAN BE DETERMINED USING SOUND

- Sound speed
- Sound attenuation
- Molecular Relaxation
- Density
- Acoustic Nonlinearity
- Viscosity

 Bulk Modulus/Density

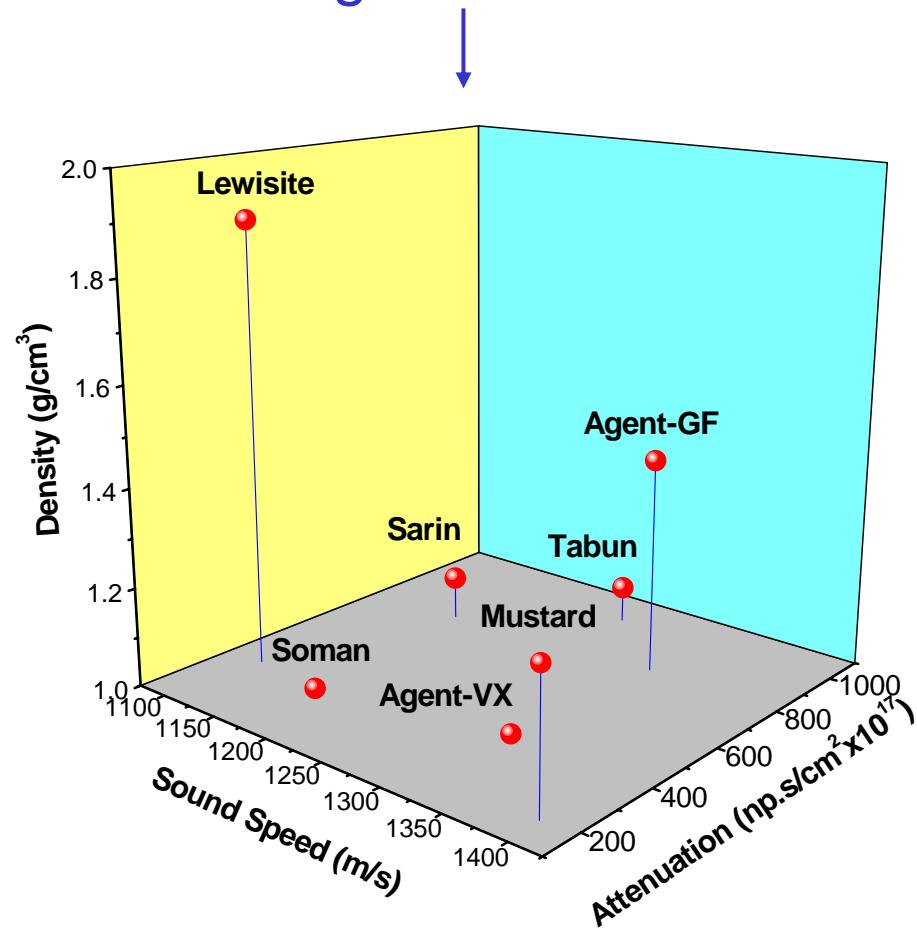
Viscous drag, thermal effects, scattering



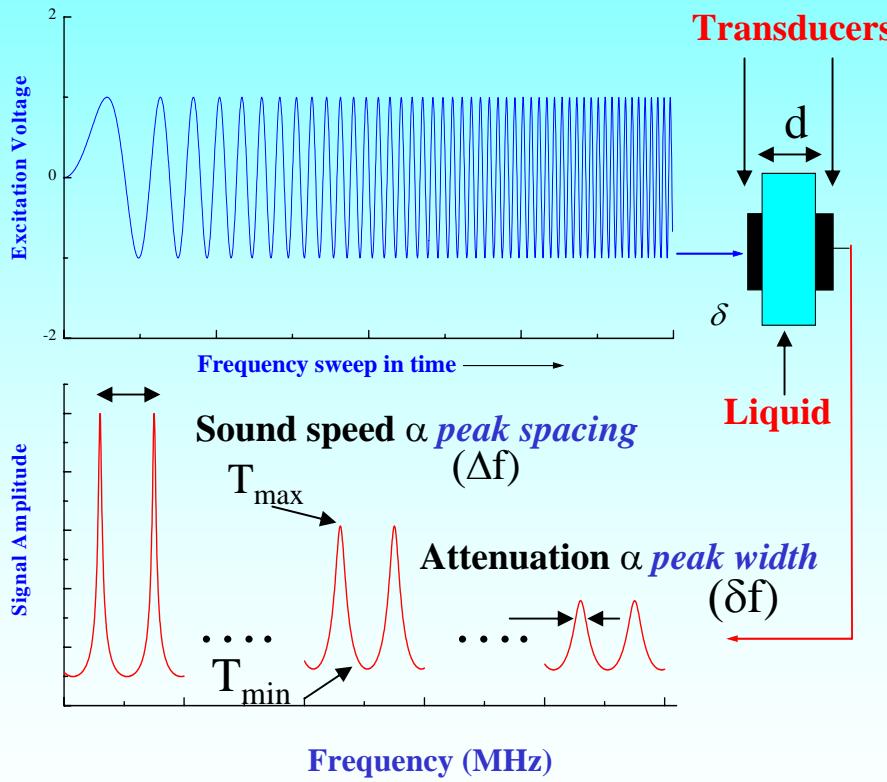
*Liquids, gases, mixtures, emulsions, suspensions, etc.*

# Swept Frequency Acoustic Interferometry

SFAI Instrument and CW agent identification



# Determination of Sound Speed and Sound Attenuation



**Sound speed:**

$$c_L = 2d\Delta f$$

**Attenuation:**

$$1. \quad \delta f = \frac{2c_L}{\pi\sigma d} + \frac{c_L\alpha_L(f)}{\pi}$$

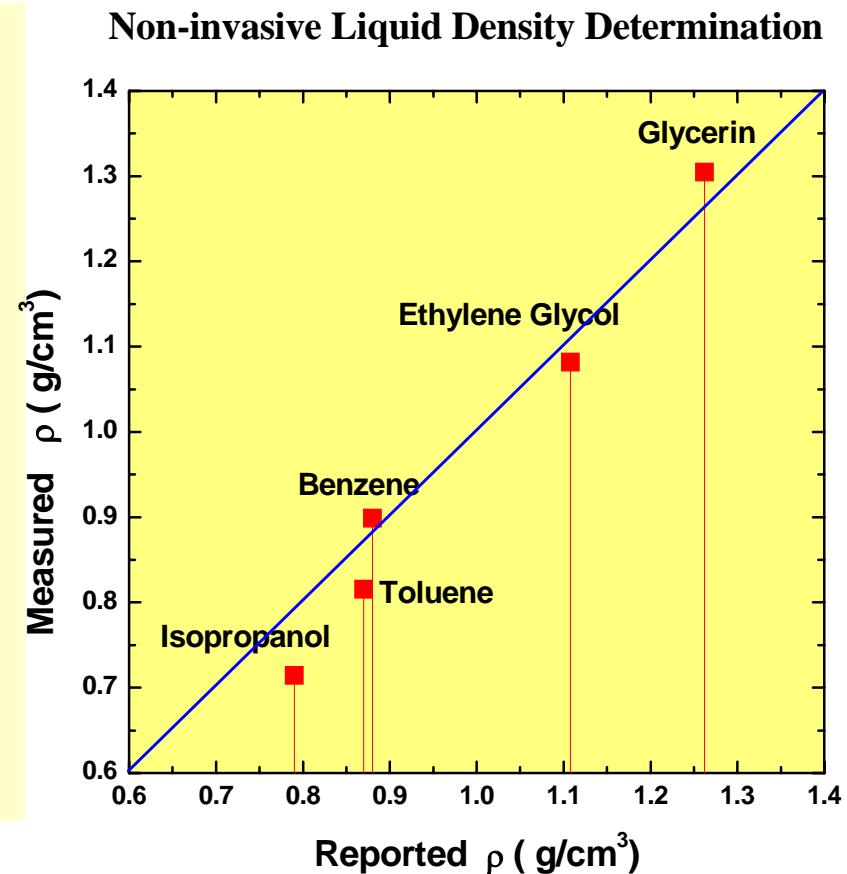
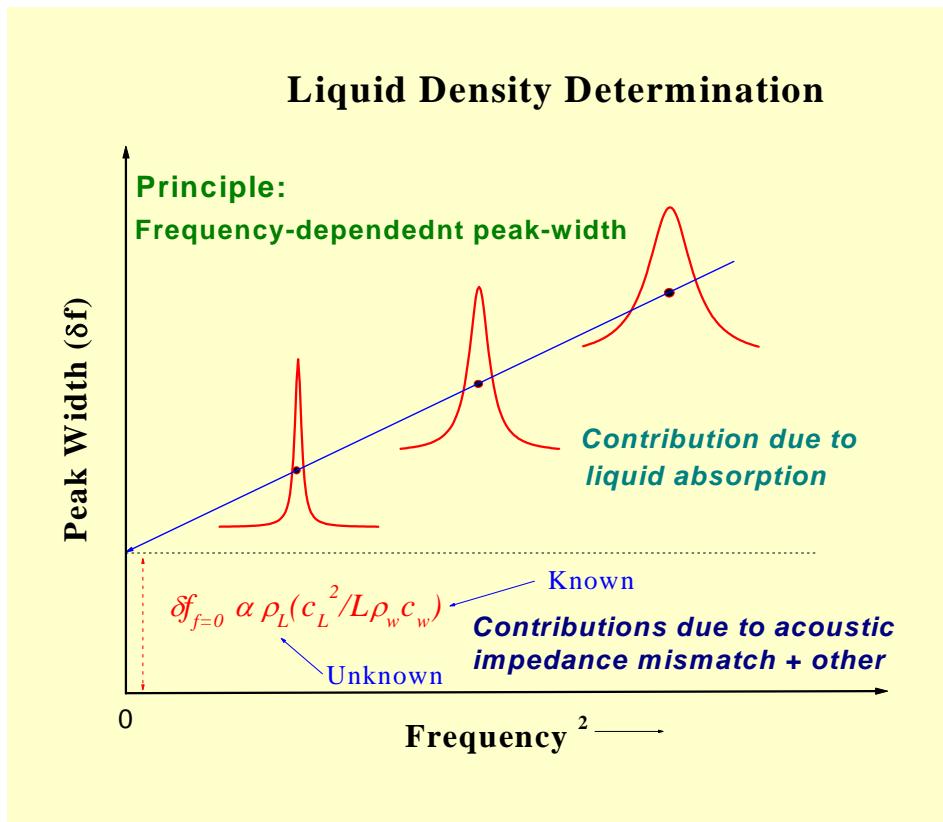
$$2. \quad \sqrt{\frac{T_{\min}}{T_{\max} - T_{\min}}} = \frac{2}{\sigma} + \alpha_L(f)d$$

**Impedance ratio:**

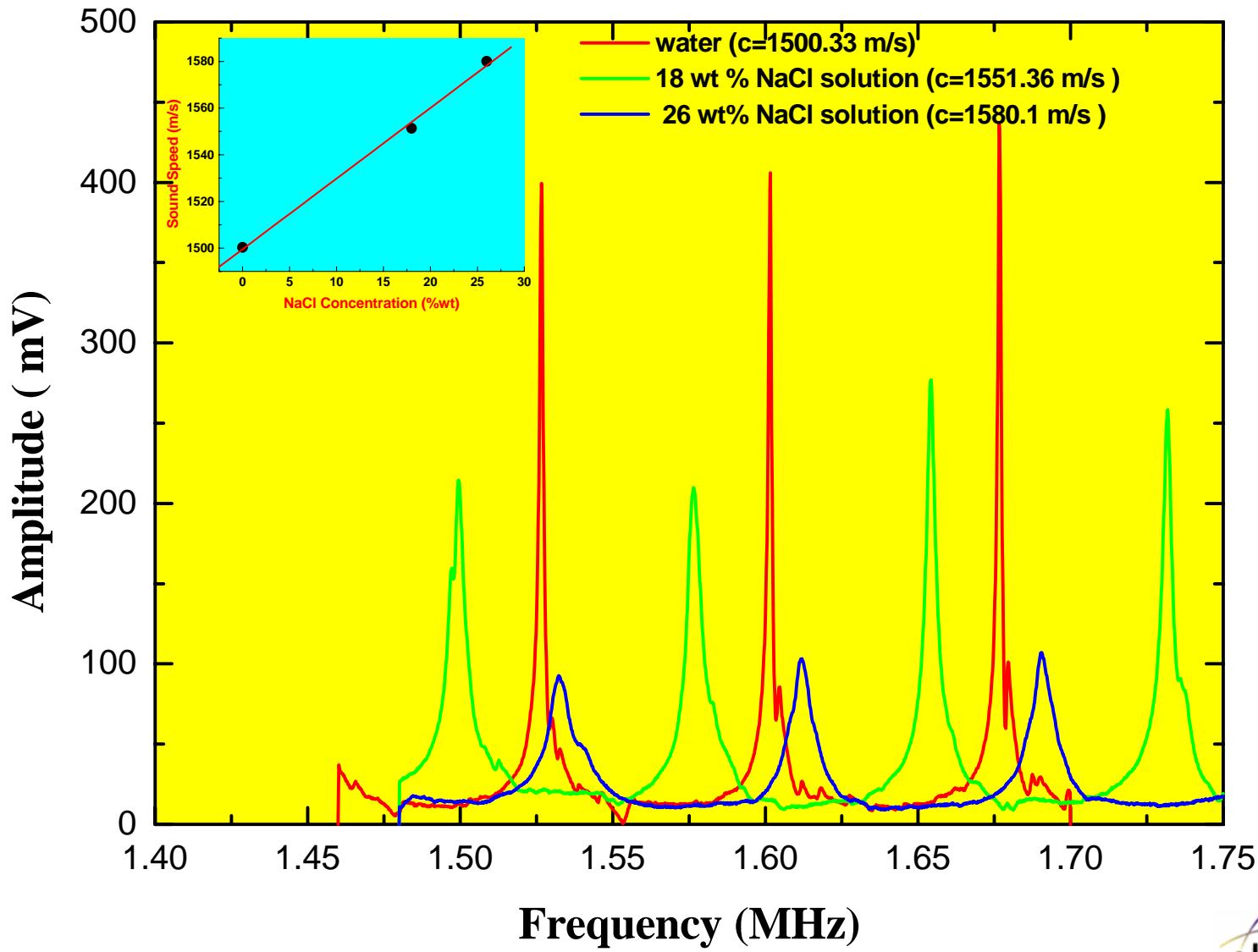
$$\sigma = \frac{z_w}{z_L} + \frac{z_L}{z_w}; \quad L = \text{liquid} \quad w = \text{wall}$$

$d$ =path length;  $T$ =transmission amplitude;  $f$ =frequency;  $\alpha$ =sound attenuation

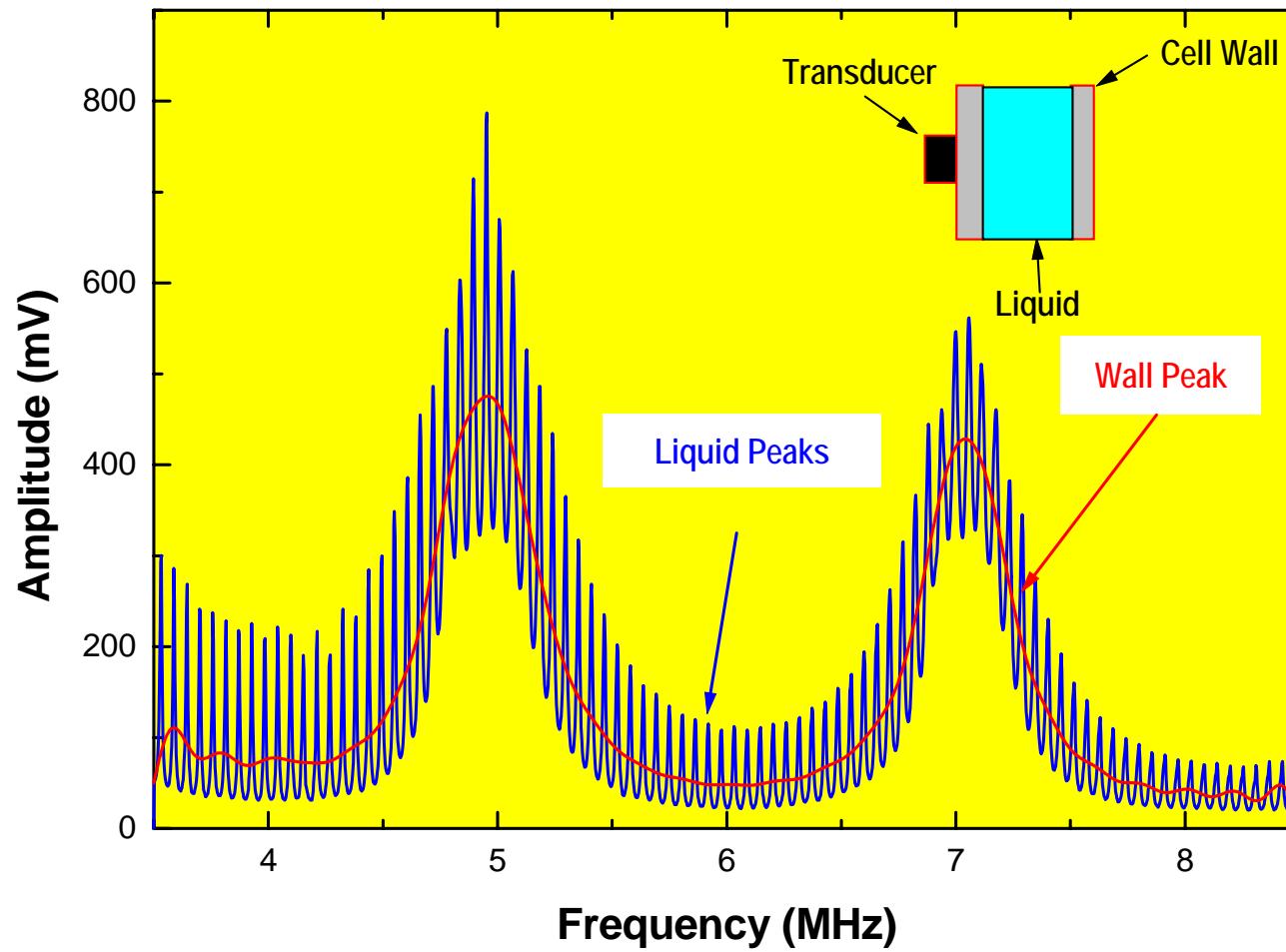
# Non-Invasive Liquid Density Determination Using SFAI



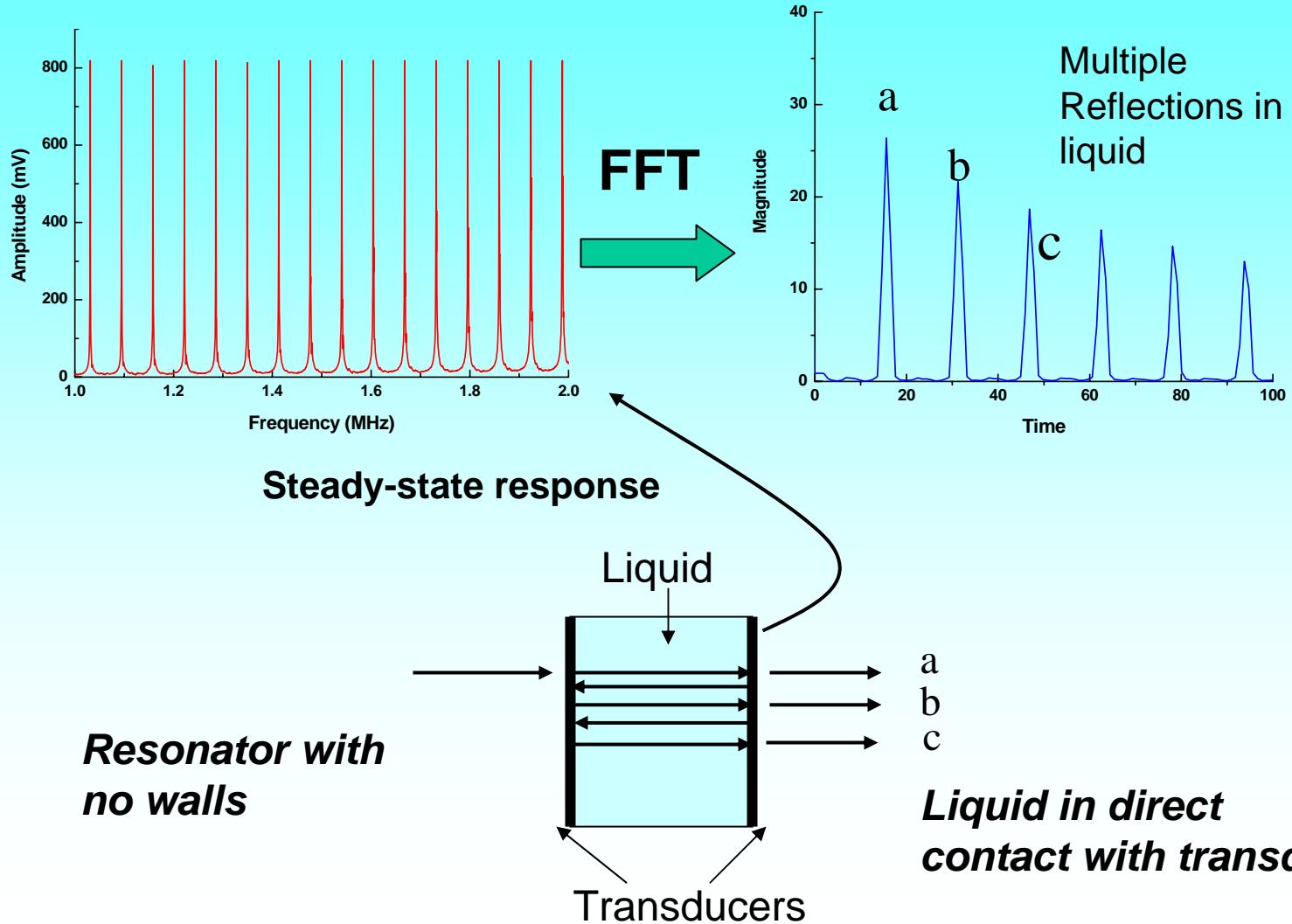
# Effect of Salt Concentration on Sound Propagation



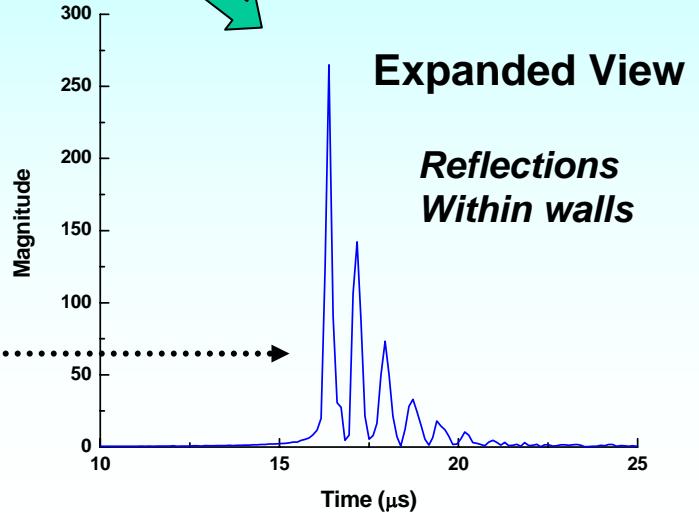
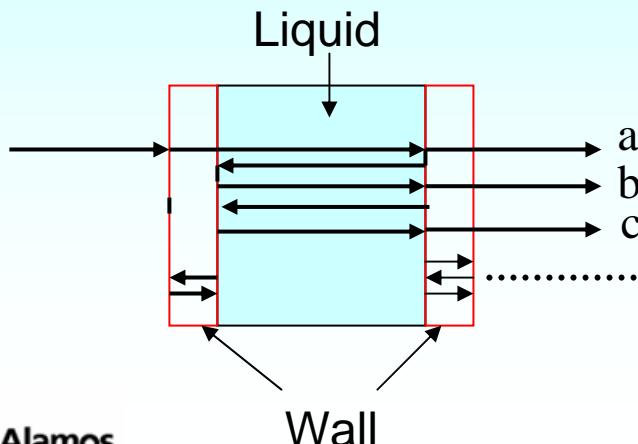
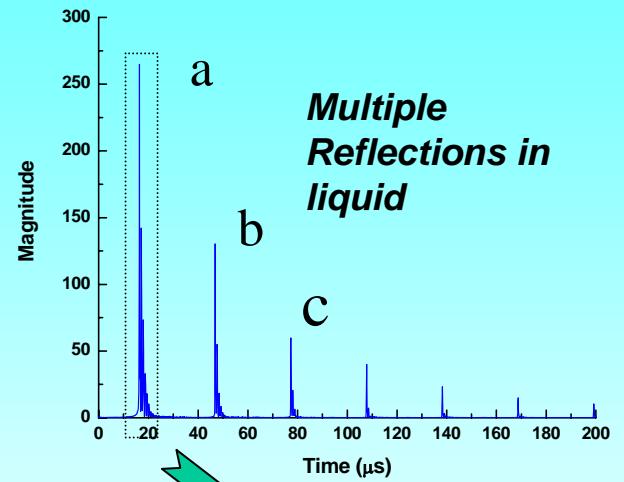
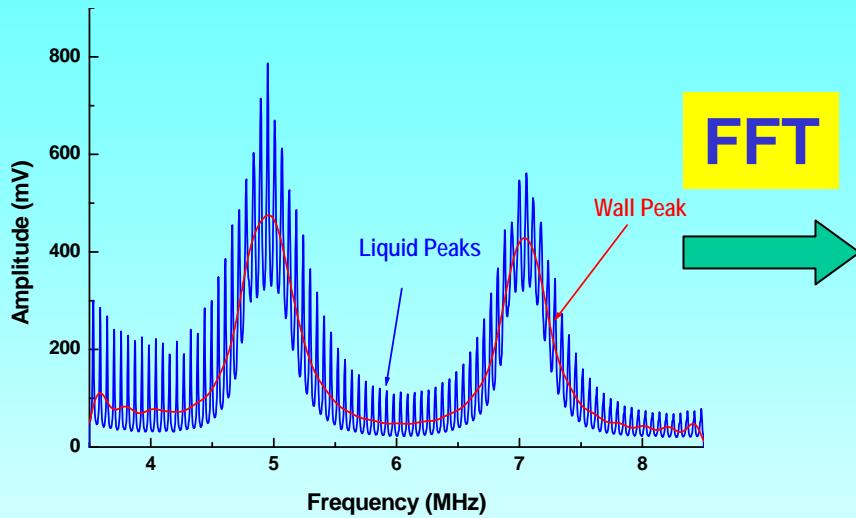
# Interference Pattern in a Container with Thick Wall



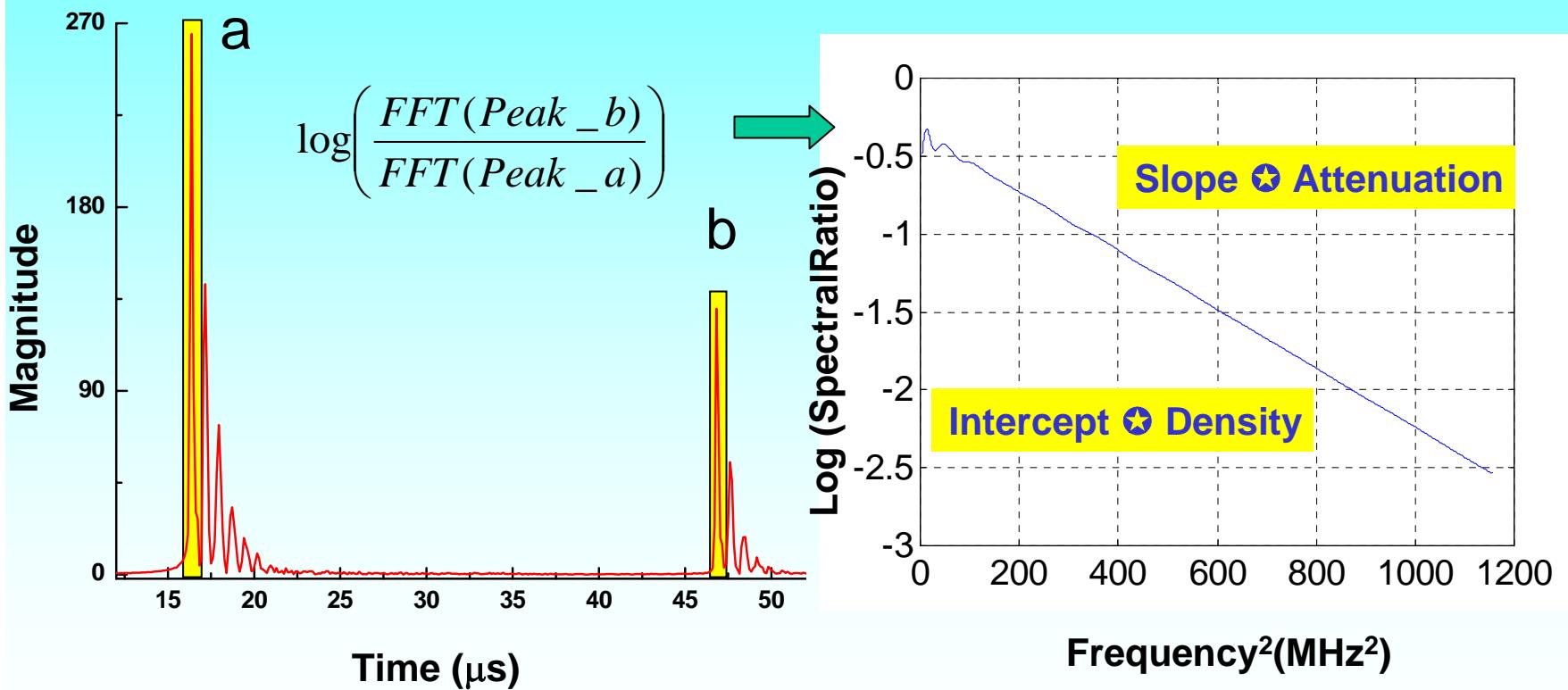
# Frequency-Domain vs. Time-Domain



# Frequency-Domain vs. Time-Domain



# Liquid Attenuation and Density Determination



# Areas of Application

## National Security:

Chemical weapons verification and identification  
Counterproliferation, Nonproliferation  
Counterdrug, customs and drug interdiction

## Basic Research:

Material characterization, imaging, sound-air interaction etc.

## Biomedical:

Noninvasive intra-cranial and intra-ocular pressure, diagnostics  
Blood glucose, body fluids, tissue characterization, etc.

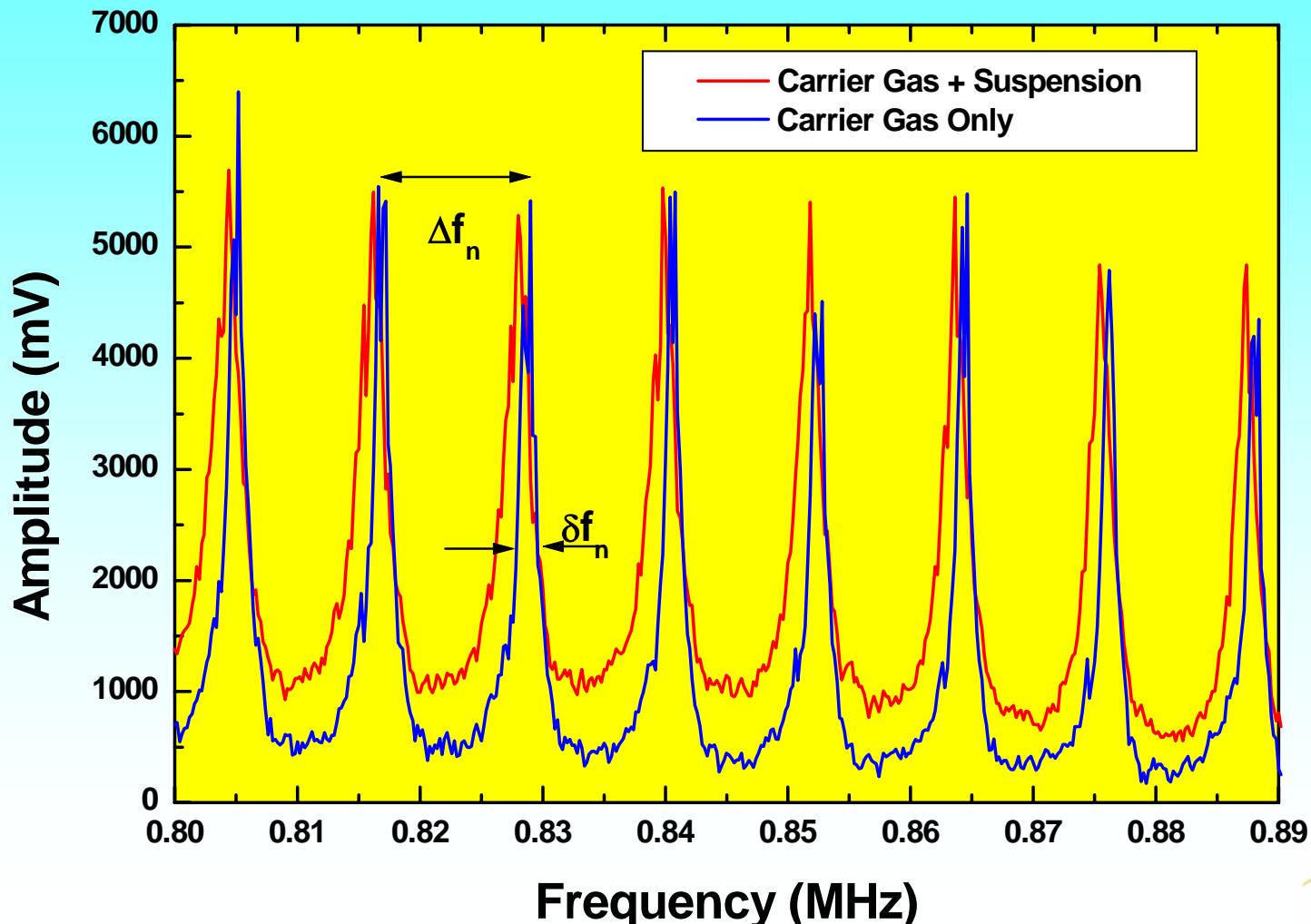
## Industrial:

*Chemical & Pharmaceutical* - Process control and characterization  
*Petroleum* - Down-hole fluid monitoring  
*Food & Beverage* - Quality control, spoilage

## Environmental Sensors:

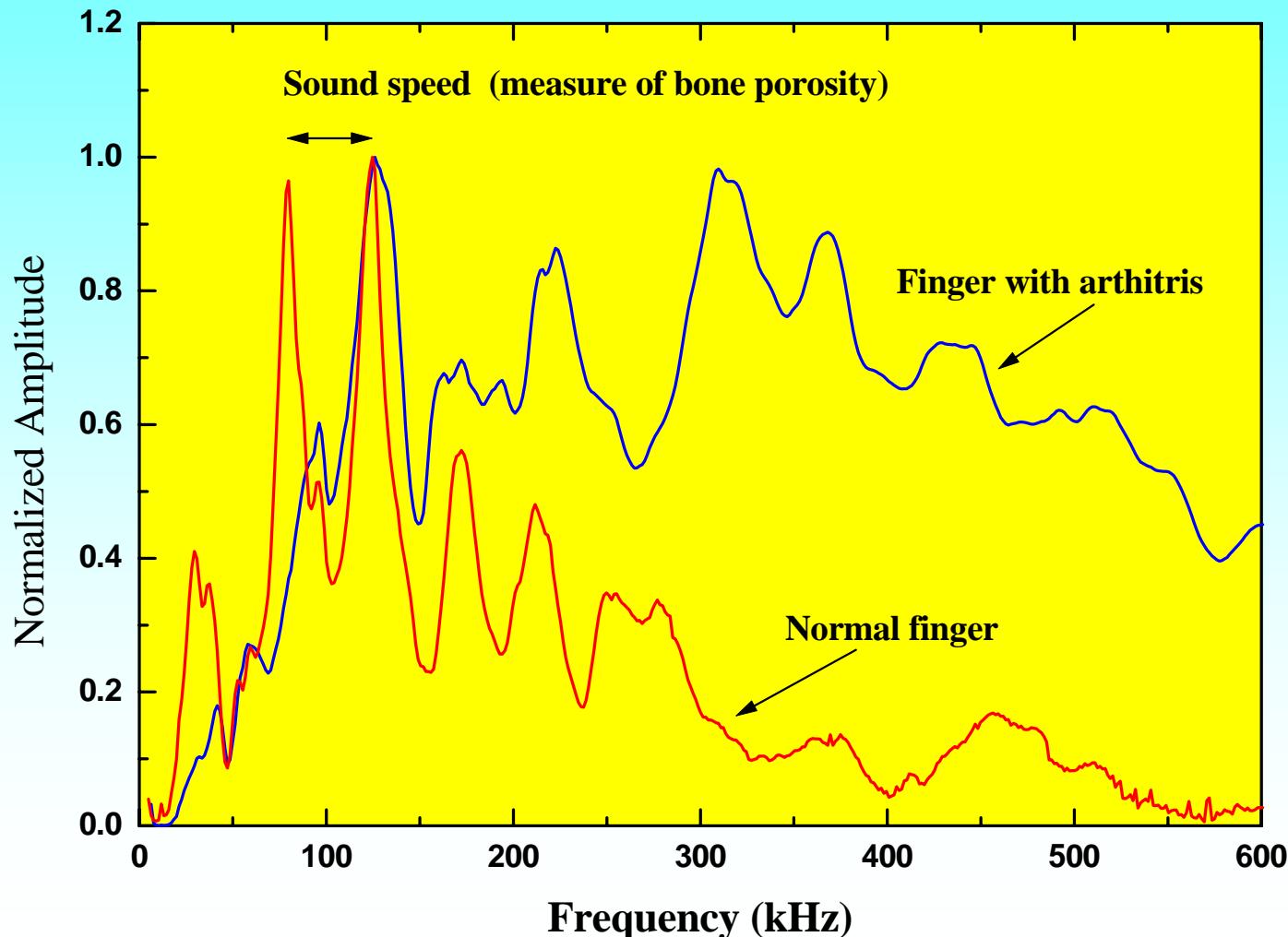
Water and air quality monitoring

# Noninvasive Detection of Aerosol in Sealed Container using SFAI

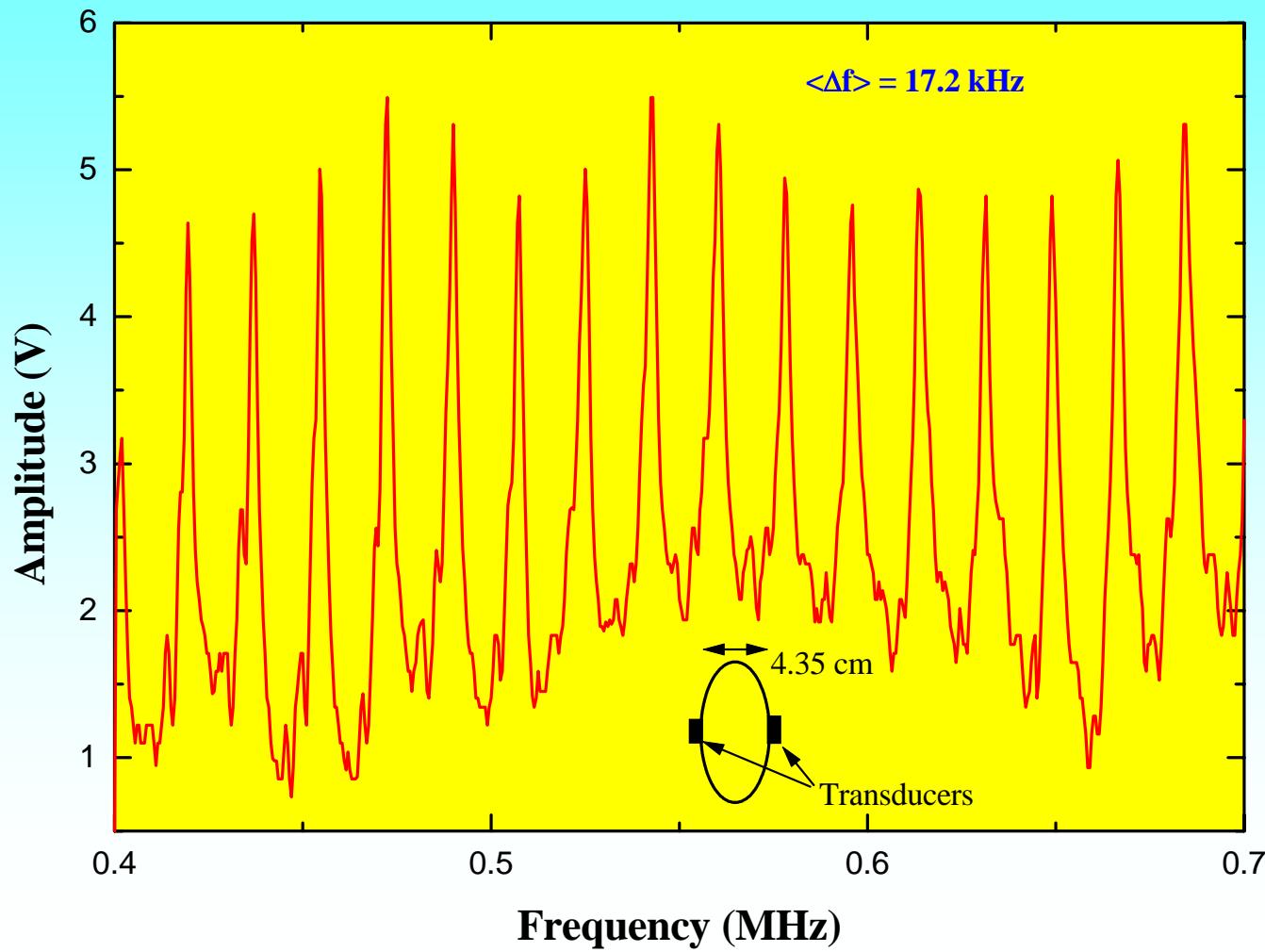


# Application of SFAI in studying bone joints for diseases

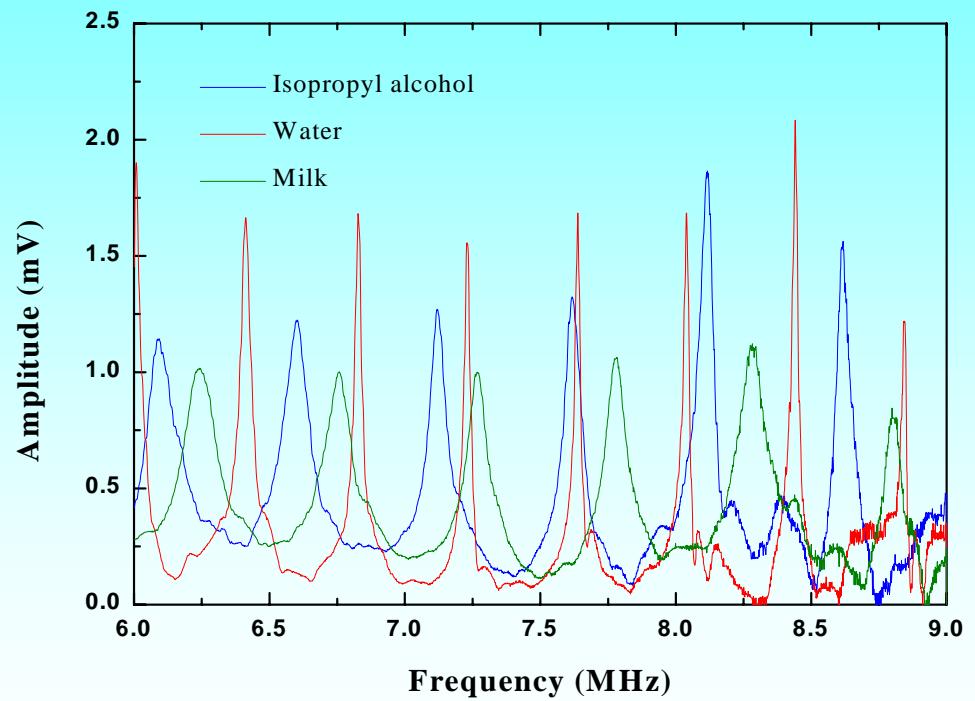
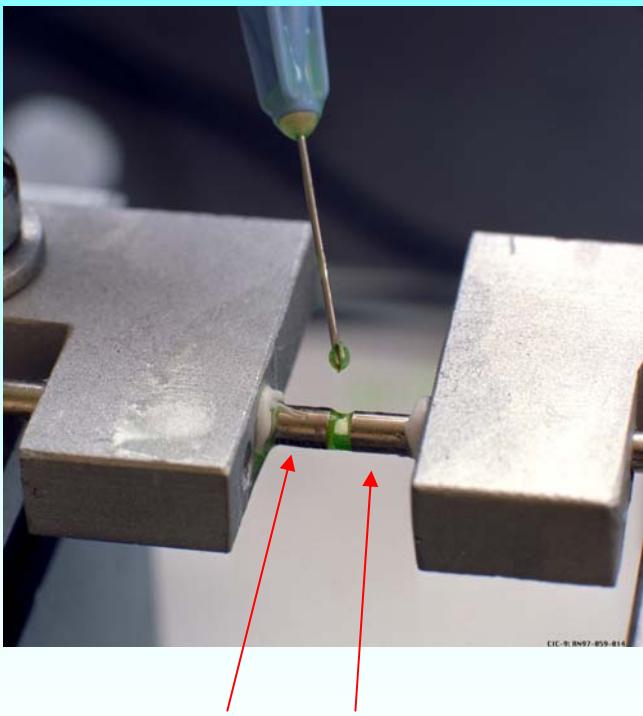
## Spectra of Bone Joints



# Noninvasive Characterization of Eggs using SFAI

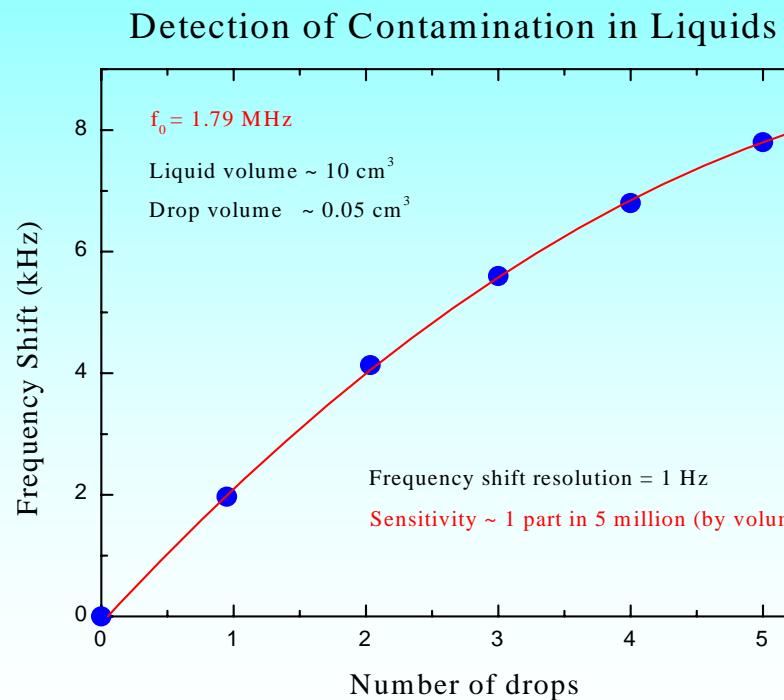
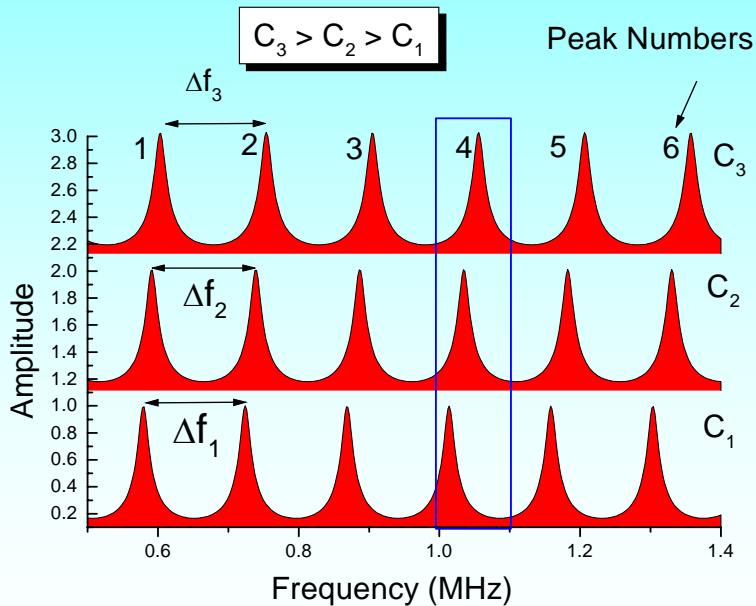


# SFAI Characterization of a Single Drop of Liquid

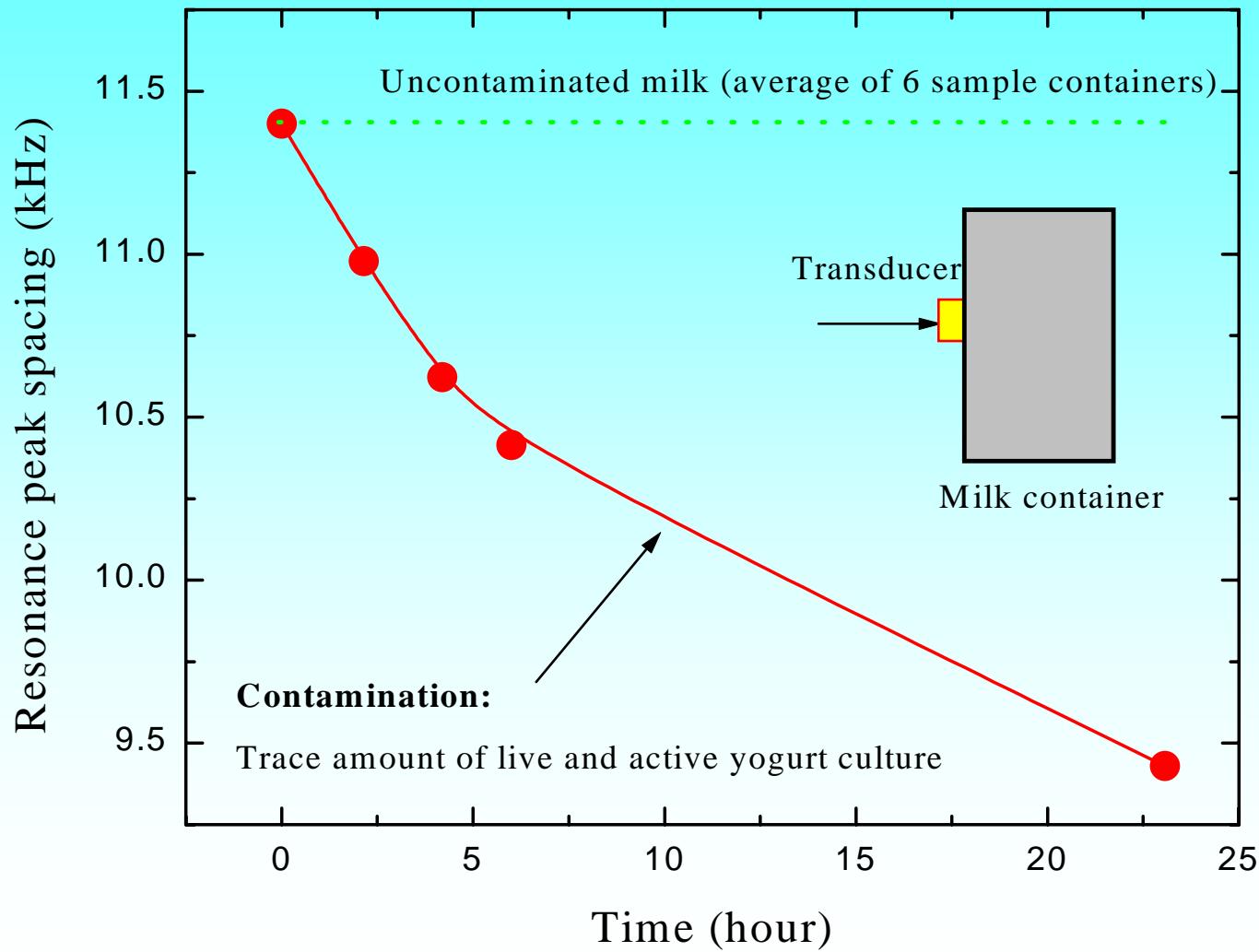


# Sensitivity of SFAI Technique

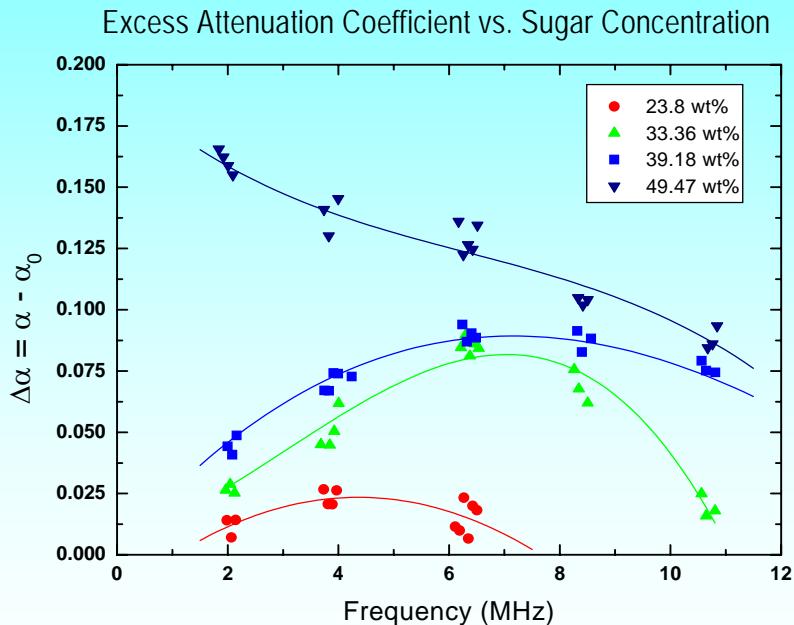
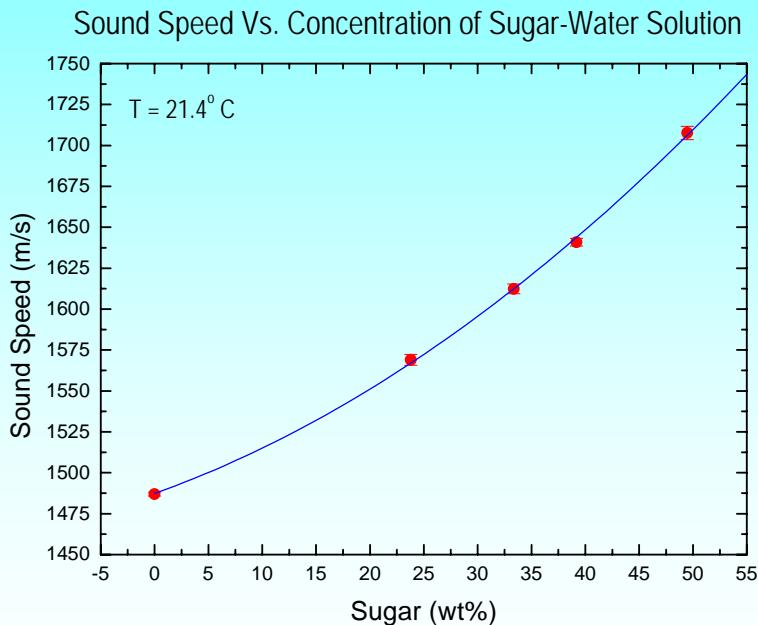
## *Single Peak Tracking*



## Time Study of Contaminated Milk

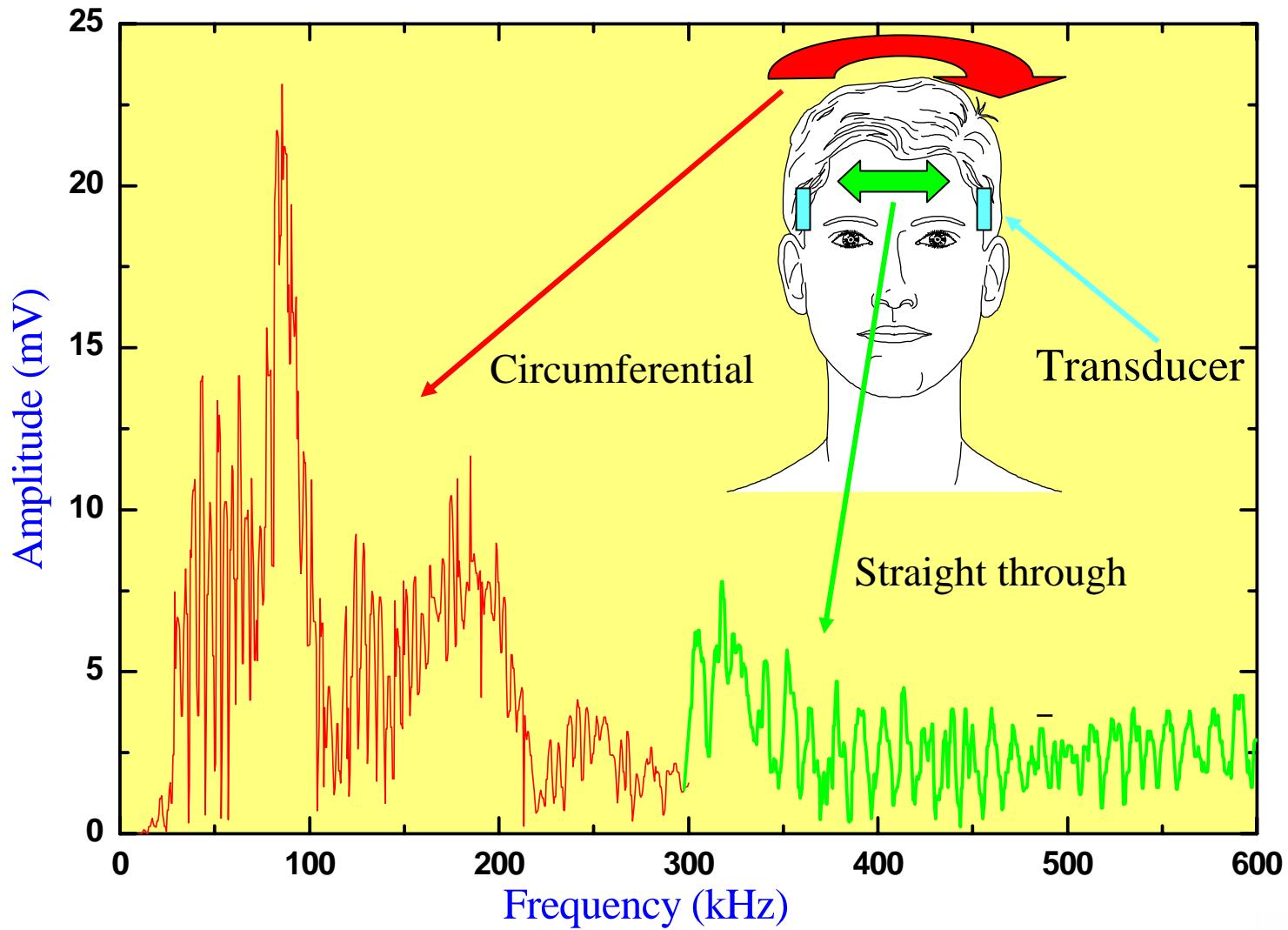


# Measurement of Concentration of Sugar using SFAI



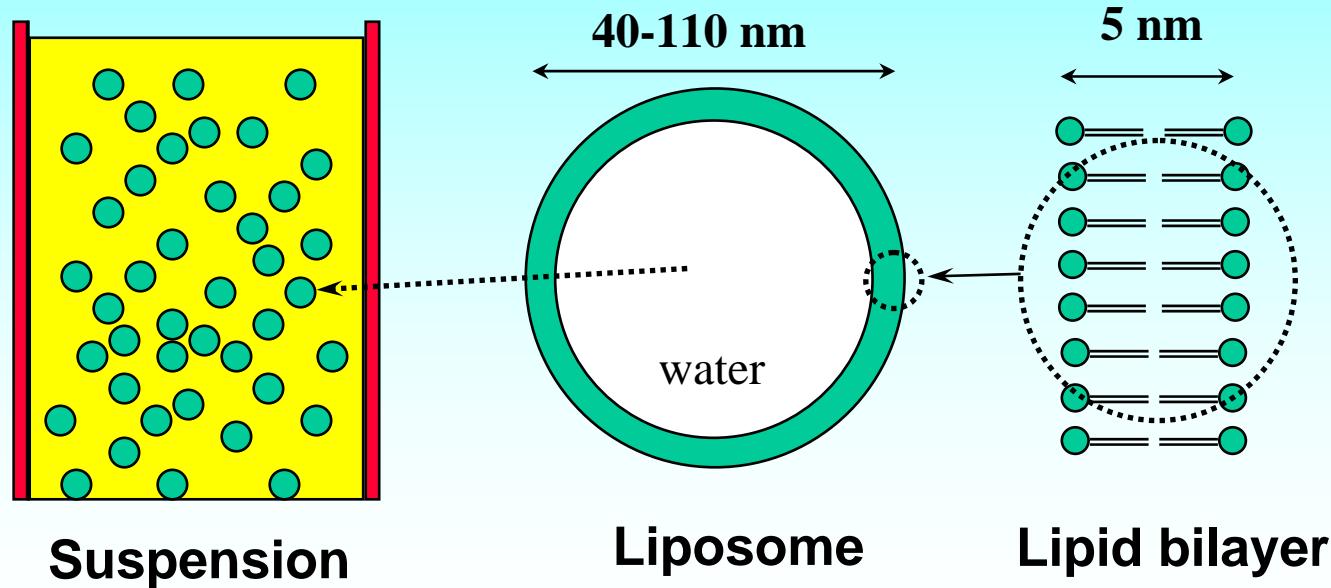
Sound speed and sound attenuation as a function of frequency can be noninvasively monitored.

## Frequency Scan of a Human Head

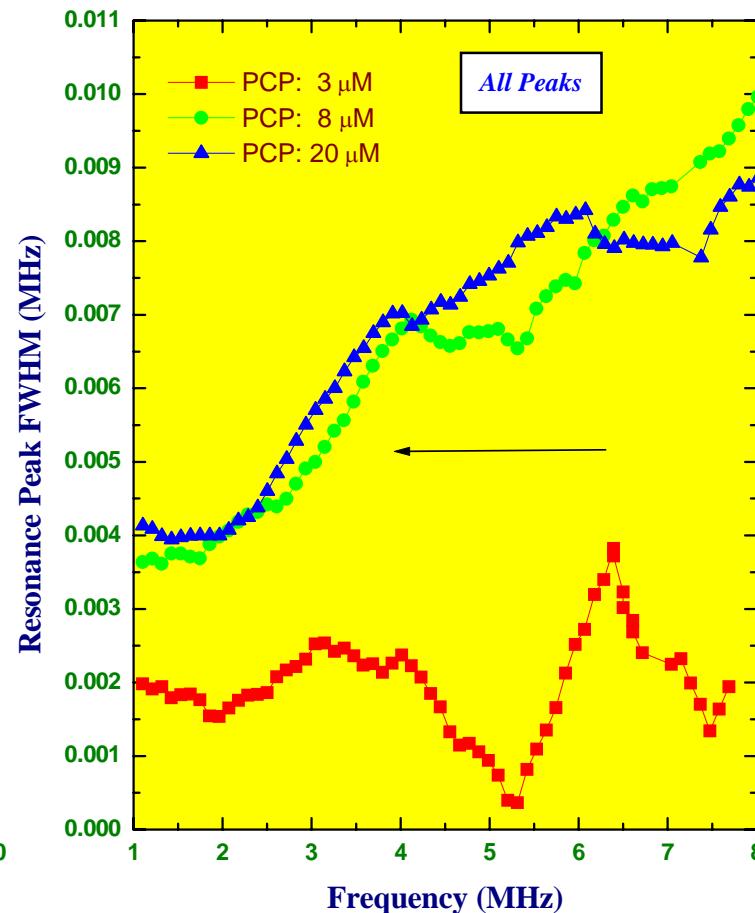
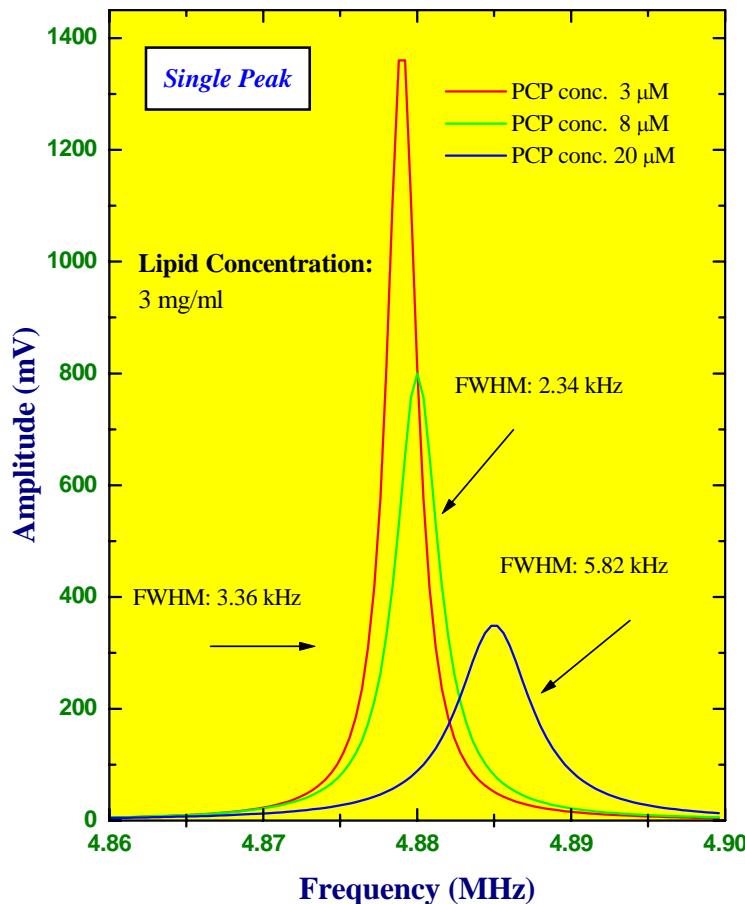


# Broad-Spectrum Toxicity Sensor for Monitoring Water Pollutants

Effect on liposomes is monitored using SFAI



# Effect PCP on Liposome Suspension: Sound Attenuation



# Important Advantages of Ultrasonic Interferometry

- Does not require flat transducer response over a large frequency range which is extremely difficult to achieve.
- Absolute amplitude information is not important
- Requires very little power (~ a few mW) for high quality measurement. Safe for working with explosives and biomedical applications.
- Very high signal-to-noise ratio without any signal averaging
- Arbitrary frequency range can be studied with any desired frequency resolution.